**Hubble’s Law—17 Oct**

- Hubble’s Law: More distant galaxies are moving away faster. 
  Speed = H \times Distance
- Universe is expanding
- Universe started with a Big Bang
- Age of the universe

**Hoag’s Galaxy**

**Coma Cluster**

- NGC4881, central galaxy in Coma Cluster

**Milky Way Galaxy**
Hubble’s Law

- Velocity $V$ is proportional to distance $D$
  - $V = H \times D$
- Demo: Let Coma & Hoag’s Galaxy move according to Hubble’s Law
  1. If Coma moves one meter, how much should Hoag move?
     a. 1 m
     b. 3 m
     c. $\frac{1}{3}$ m
     d. 9 m
     e. $\frac{1}{9}$ m

<table>
<thead>
<tr>
<th>Dist</th>
<th>Speed</th>
<th>Milky Way</th>
<th>Coma</th>
<th>Hoag’s Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Mpc</td>
<td>0 km/s</td>
<td>0 km/s</td>
<td>6,000 km/s</td>
<td>18,000 km/s</td>
</tr>
<tr>
<td>100 Mpc</td>
<td>6,000 km/s</td>
<td>6,000 km/s</td>
<td>100 Mpc</td>
<td>300 Mpc</td>
</tr>
</tbody>
</table>

2. Hoag is 3 times as far as Coma. Is this still true in the future? Was this true in the past?
   - a. YY
   - b. YN
   - c. NY
   - d. NN

Hubble’s Law

- $V = H \times D$
- H’s Law => Universe began in a Big Bang
  - Universe was very dense
  - What became Milky Way was very close to what became Coma & Hoag’s Galaxy.
- Current physics can explain universe $10^{-16}$s after Big Bang, when proto-Coma was 1 mm from proto-us.

3. If we are in Coma, would H’s Law apply?
   - a. Y
   - b. N
What does value of H imply?

- $V = H \times D$

4. What is the value of Hubble’s constant? Express your answer in km/s/Mpc

- $H = \frac{V}{D}$
  
  - $= \frac{30000 \text{ km/s}}{470 \text{ Mpc}} = 30000 \text{ km/s} / (470 \text{ Mpc})$
  
  - $= 64 \text{ km/s/Mpc}$
  
  - $= 64 \text{ km/s} / (3 \times 10^{19} \text{ km})$
  
  - $= 1 / (15 \text{ Byr})$

What does value of H imply?

- Write H’s law in more familiar form
  
  - $D = V \times (1/H)$
  
- $1/H = D/V$
  
  - $= (470 \text{ Mpc}) / 30000 \text{ km/s}$
  
  - $= 15 \text{ Byr}$

5. Some matter that was very near us soon after the Big Bang was moving at 30,000 km/s. How far has it moved in 1 Byr? Is 15 Byr?

Value of H implies age of universe

- Write H’s law in more familiar form
  
  - $D = V \times (1/H)$

- $1/H = D/V$
  
  - $= (470 \text{ Mpc}) / 30000 \text{ km/s}$
  
  - $= 15 \text{ Byr}$

  - Some matter that was very near us soon after the Big Bang was moving at 30,000 km/s.

  - The age of the universe is 15 Byr.
    - In 15 Byr, that matter has moved 470 Mpc and become part of a galaxy.
    - In 1 Byr, that matter has not moved far enough to be part of a galaxy. U is older than 1 Byr.

  - Be aware: We assumed matter does not speed up or slow down.
Summarizing questions

• Why does Hubble’s Law imply a Big Bang?
• Do aliens on another galaxy also observe galaxies to move according to H’s Law?
• If the motion of matter slows down, is the age of the universe longer or shorter than 1/H?